Impact of rotor solidity on wind turbine fatigue and extreme loads

Romans Kazacoks

Supervised by: Peter Jamieson

Aim:

- Identify key influences on fatigue and extreme loads
- Develop a general trend (Ideally in the form of simple power law curves)
- Reveal and quantify effects
- Develop a cost model (showing how loads affect cost)

<u>Key factors affecting loads:</u>

- Structural parameters
- Operational parameters
- Wind conditions
- Up-scaling

- <u>Impact of rotor solidity:</u>
  - Changing the rated tip speed

$$c \sim \frac{1}{\lambda^2}\ ; \quad \tan\beta = \frac{1-a}{\lambda\mu(1+a')}$$

  - Changing the solidity without changing the rated speed:

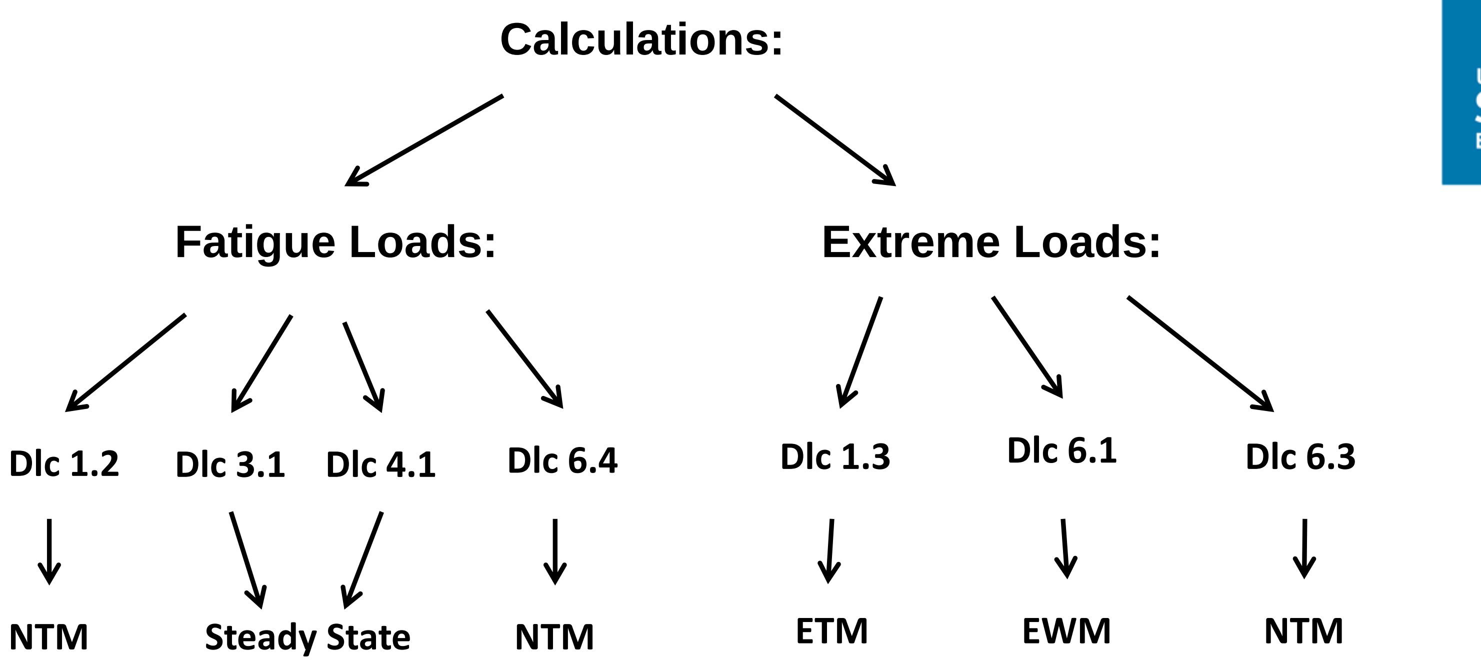
$$\Lambda\,(\lambda, x) = \frac{c\,(\lambda, x)\; C_L}{R}\ ;$$

Boundaries of study:

- Reference WT is 3MW rated power, upwind, variable speed, and pitch regulated wind turbine
- Linear scaling law is applied to adjust the mass and bending stiffness of blades
  - Blade mass is proportional to chord and blade length ($m \sim c^2 * L \;\therefore\; A_{aerofoil} = K_A c^2$)
  - Bending stiffness ($EI \sim c^4$)
  - Preserve original aerofoils

Technology challenges:

- Changes of WT features will require redesign of the control systems. It is important this can be done relatively quickly and efficiently perhaps in simplified way.
- However commercial designs will seek to reduce weight and cost using the new technology to avoid the mass penalties from modifications with similarity.



- **Dlc 1.2** – design load case, WT is at power production range and connected to the electrical load at normal turbulence model (**NTM)**. Wind speed ϵ [4:2:24] with a mean yaw misalignment of $\pm 8^{\circ}$.
- **Dlc 1.3** – WT is running and connected to the electrical load at extreme turbulence model (**ETM**) . Wind speed ϵ [9.2, 11.2, 13.2, 20, 25].
- **Dlc 3.1 –** WT starts up from standstill or idling to power production conditions .
- **Dlc 4.1 -** WT normal shut downs from power production to a standstill or idling to conditions.
- **Dlc 6.1 –** WT is at an idling condition (50 m/s) with a mean yaw misalignment of $\pm 8^{\circ}$ using the turbulent extreme wind model (**EWM**).
- **Dlc 6.3 –** WT is at an idling condition (40 m/s) with extreme yaw misalignment of $\pm 30^{\circ}$ using the turbulent extreme wind model (**EWM**).
- **Dlc 6.4 –** WT is at an idling condition (3, 30, 35 m/s) with a yaw misalignment of $\pm 8^{\circ}$ using the turbulent normal wind model (**NTM**).

Wind condition:

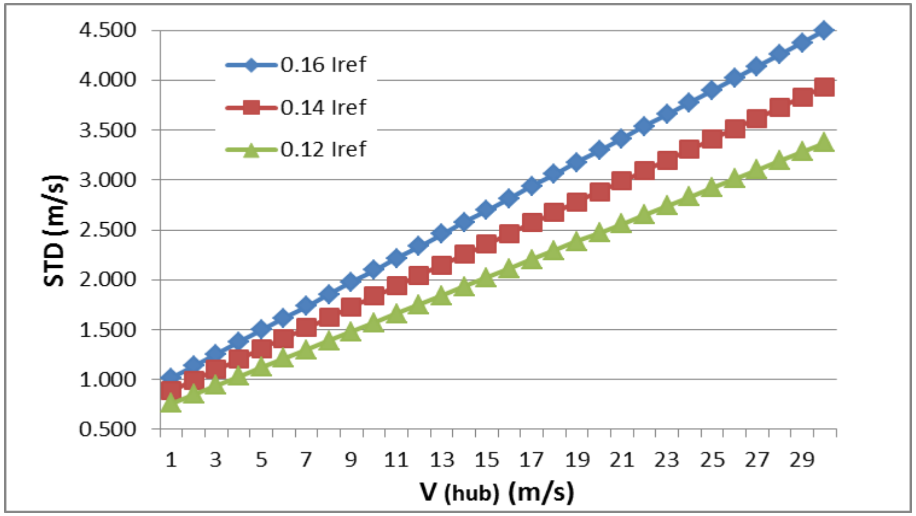
Wind turbulence was based on Kaimal:

Where, β is longitudinal scale parameter. β= 0.7*z if z≤ 60m or β= 42 m if z > 60m

- XLu is longitudinal direction or along the average wind flow velocity
- XLv is lateral or perpendicular to the longitudinal direction
- XLw is upward direction or perpendicular to both above mentions directions.

Axis components	XLu	XLv	XLw
Standard deviation	σ	0.8* σ	0.5* σ
Length scale	8.1*β	2.7*β	0.66*β
Coherence decay constant	12		
Coherence scale parameter	8.1*β		

Determination of parameters for Kaimal model



Normal Turbulence model (NTM):

$$\sigma_1 = I_{ref}(0.75V_{hub} + b); \;\; b = 5.6\, m/s$$

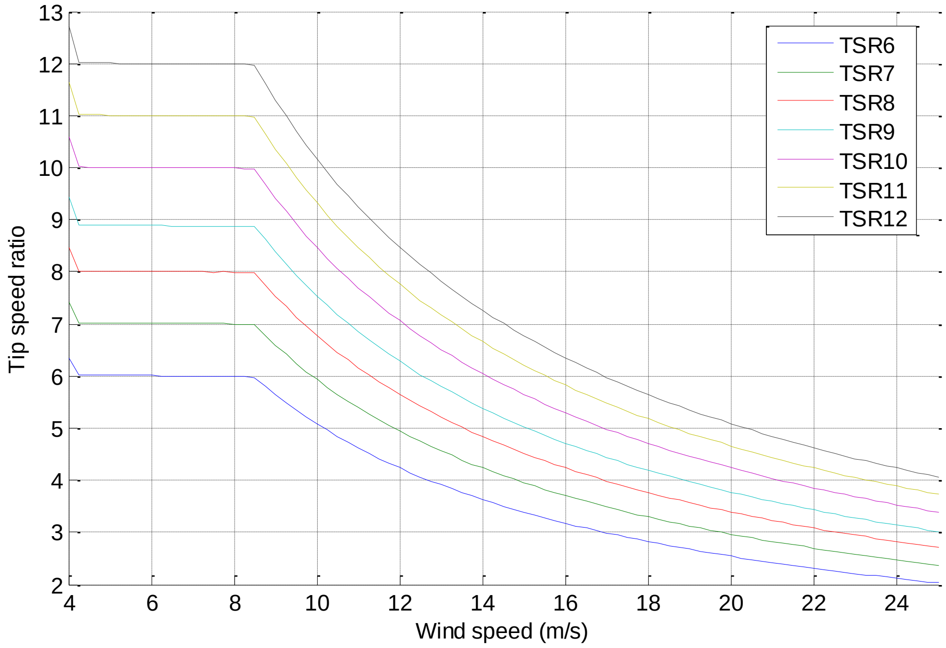
Where, V_{hub} is wind speed at the hub height, σ_1 is a fixed turbulence standard deviation, I_{ref} is expected value of turbulence intensity at 15 m/s.

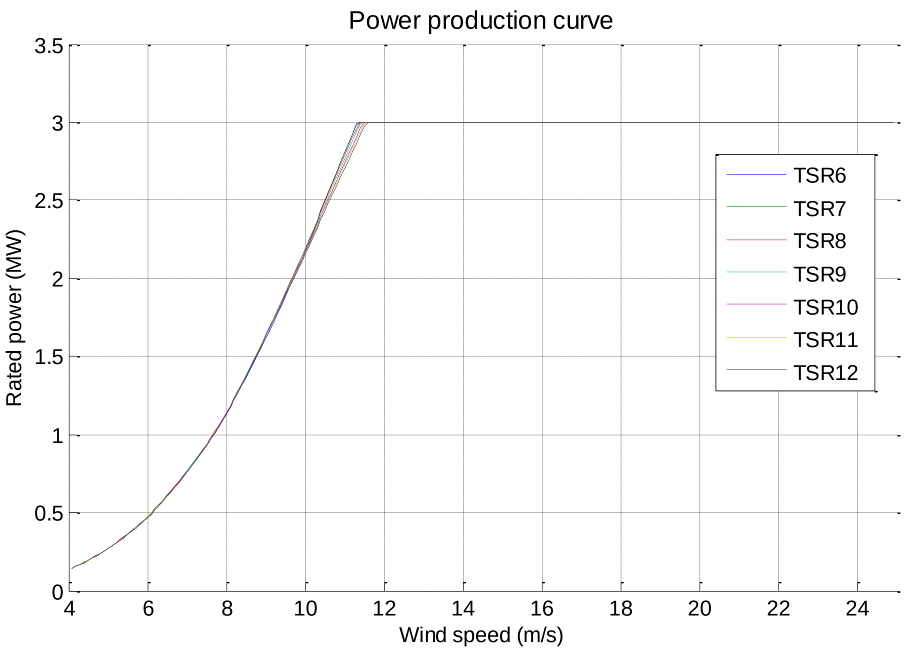
$I_{ref} = 0.16$ for high turbulence characteristics
$I_{ref} = 0.14$ for medium turbulence characteristics
$I_{ref} = 0.12$ for low turbulence characteristics

Wind turbulence class	I	II	III
V_{ref} (m/s)	50	42.5	37.5

Accuracy check:

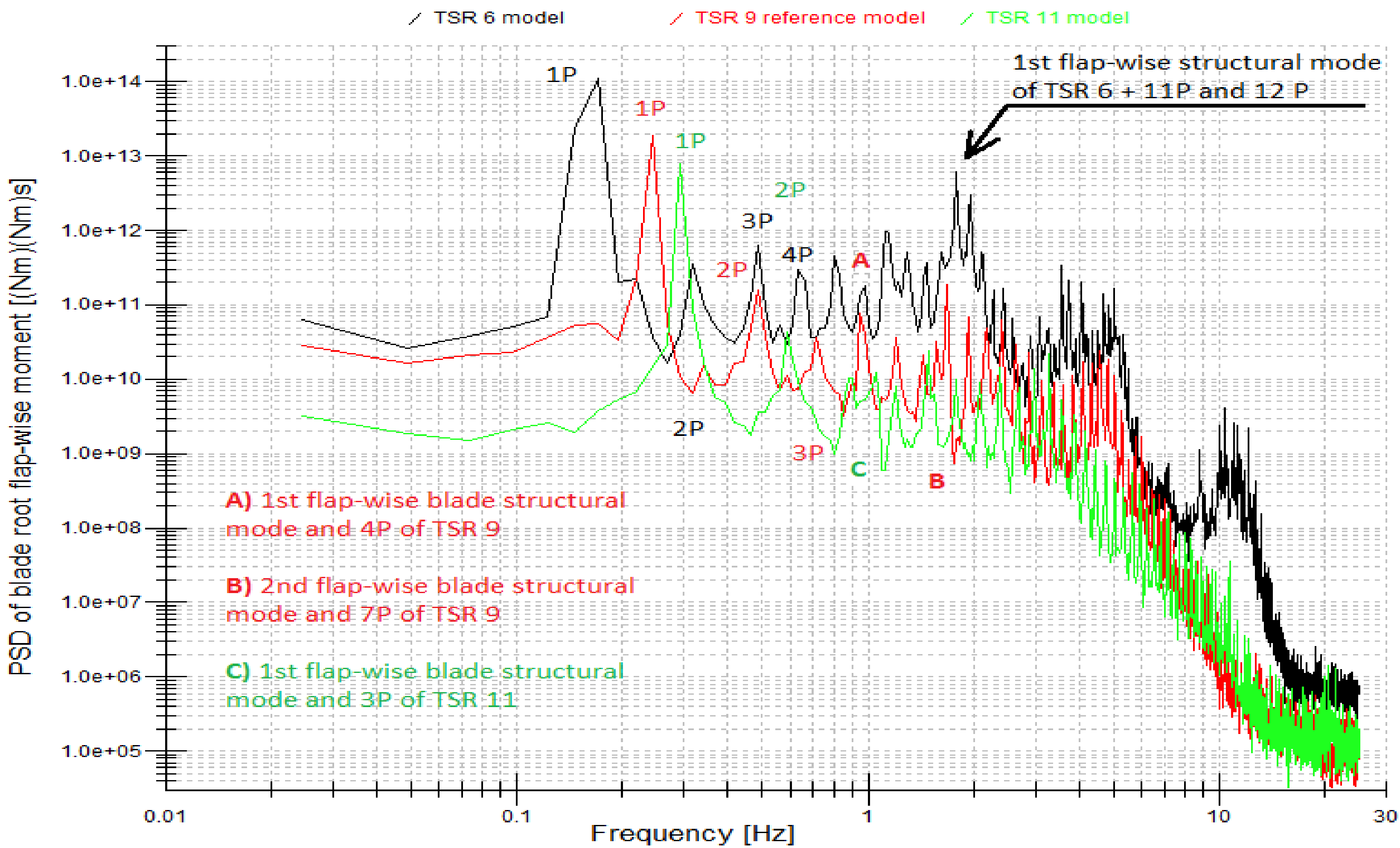
- Steady state conditions





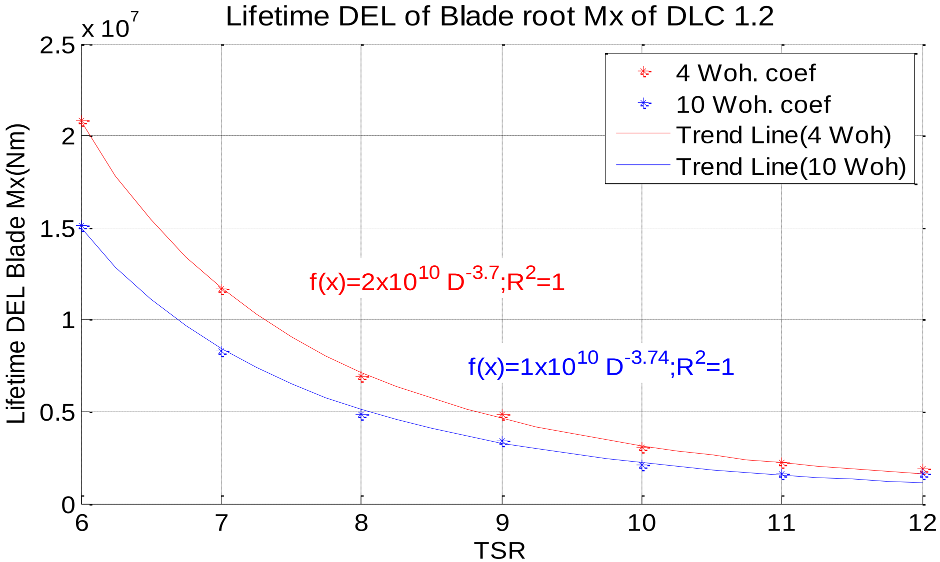
Spectral Analysis:

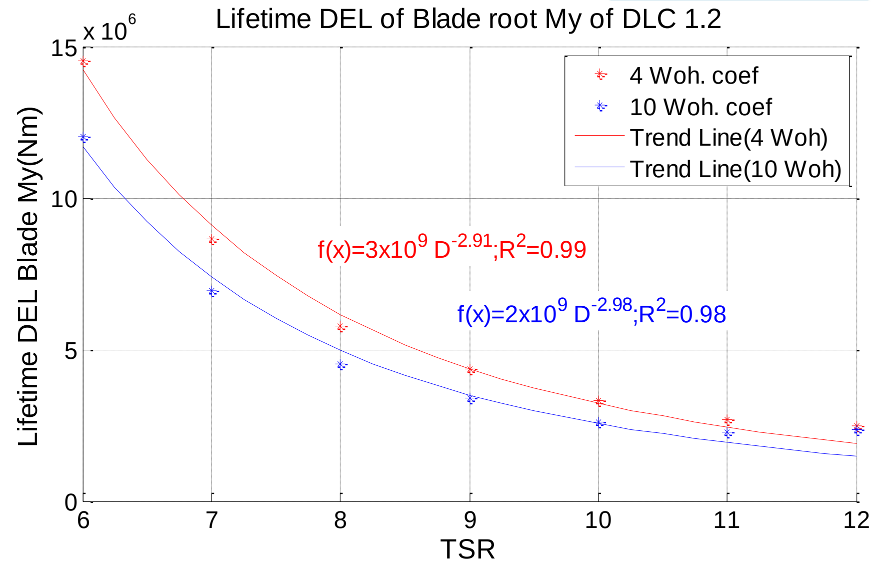
- DLC 1.2 at 14m/s average wind speed

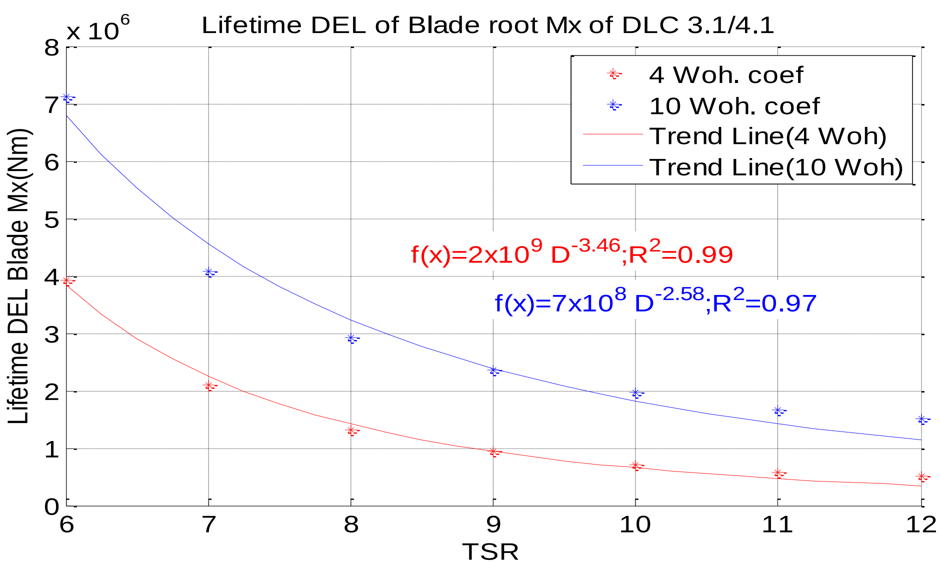


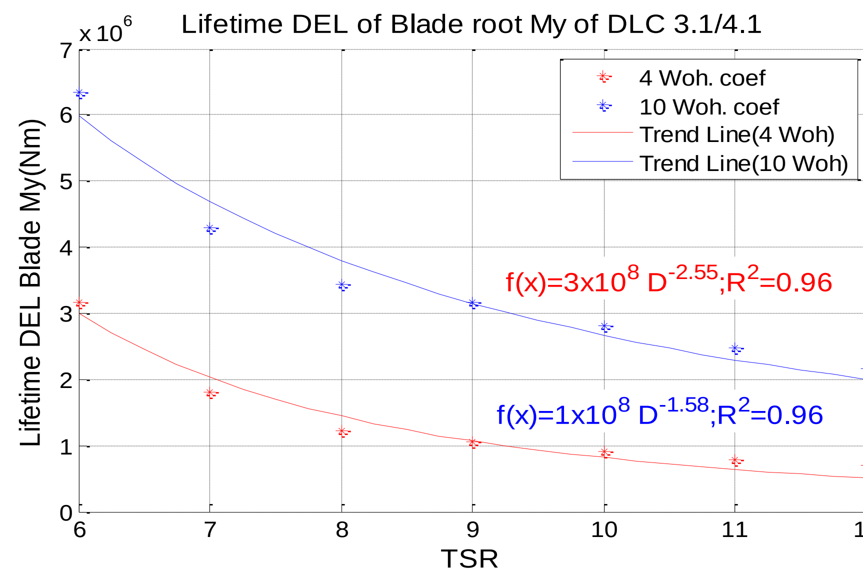
Rotor solidity: Lifetime DELs and Extreme Loads:

Fatigue: **dlc 1.2; 3.1/4.1:**



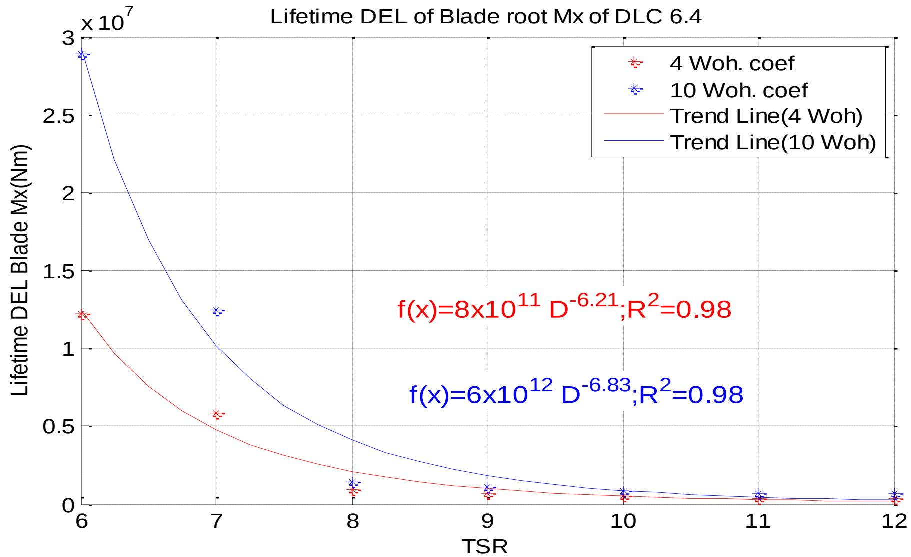


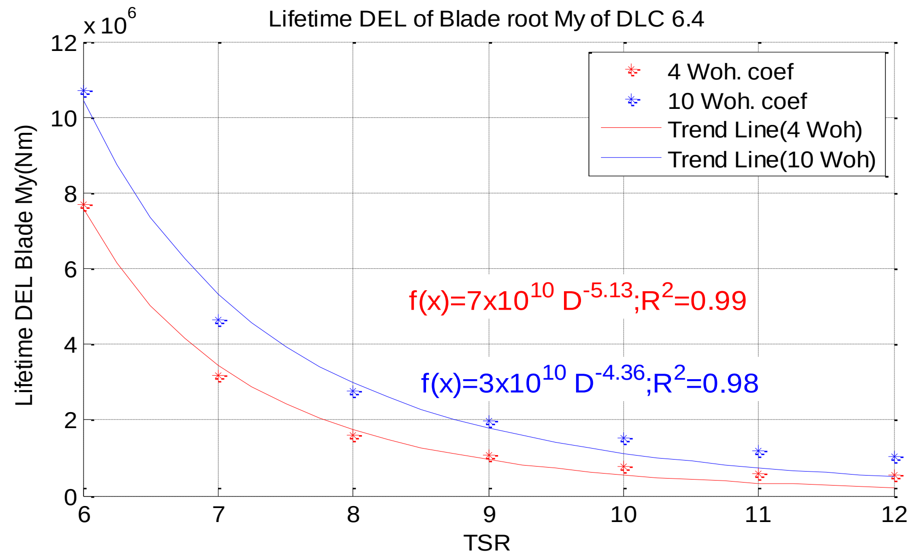


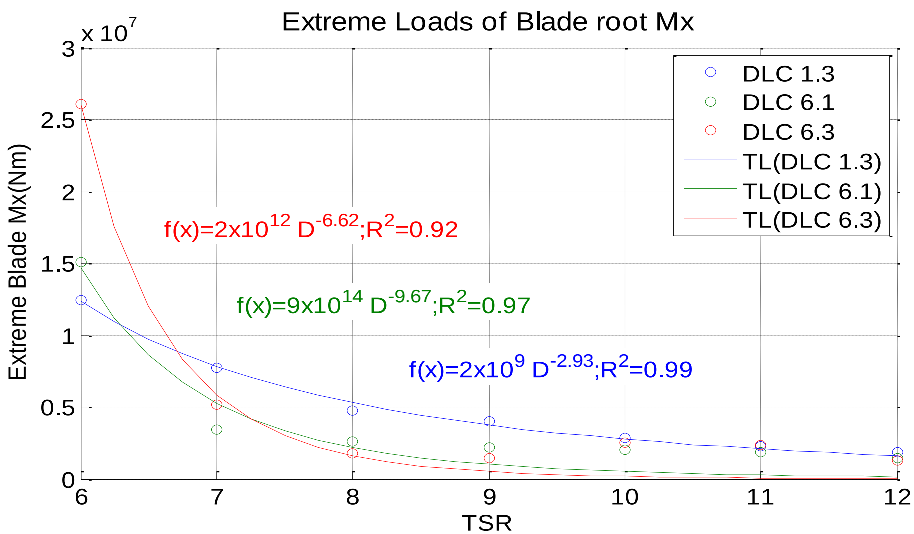


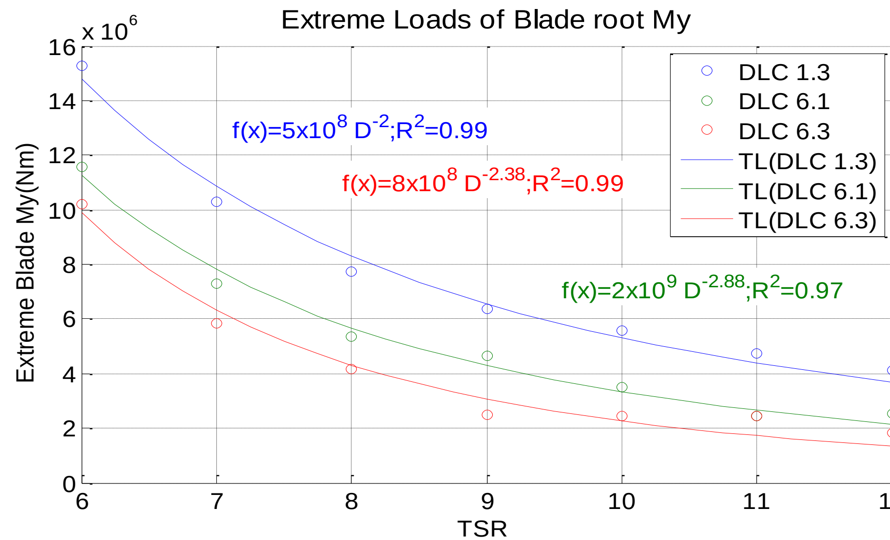
Rotor solidity: Lifetime DELs and Extreme Loads:

Fatigue **Dlc 6.4;** Extreme (**Dlc 1.3, 6.1, 6.3):**









Conclusion:

- The gained results demonstrate the modifications of TSR has influence on the fatigue and extreme loads.
- Increasing of TSR reduces fatigue and extreme loads. It can be used to reduce the amount of material at the blades root in order to reduce to the cost of wind turbine.

Future work:

- Examine the impact of TSR on aerodynamic damping
- Investigate the impact of rotor solidity:
  - Changing the solidity without changing the rated speed.

University of Strathclyde Glasgow